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ENGINEERING FEATURES

OF THE

WAIAHOLE WATER PROJECT

OF THE

WAIAHOLE WATER CO.

ISLAND OF OAHU, TERRITORY OF HAWAII

By Chas. H. Kluegel, Mem. Am. Soc. C.E.

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Electric storage-battery locomotive, and train of Koppel one-yard all-steel dump cars, near the South Portal of the main tunnel, Waiawa Gulch.

Engineering Features of the Waiahole Water Project of the Waiahole Water Company.

ISLAND OF OAHU, TERRITORY OF HAWAII

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The general plan or scheme of development adopted was that recommended by Mr. J. B. Lippincott, C.E., who made an exhaustive study of the project, going fully into the past history and study already made by Mr. J. Jorgensen and other parties, and reported to the Board of Directors of the Oahu Sugar Co., Ltd., under date of August 19, 1911.

Mr. Lippincott was assisted in this work by Mr. W. A. Wall. During the following two years, the Waiahole Water Co., Ltd., was organized, and Mr. H. K. Bishop was appointed Chief Engineer of the project in January, 1913, and the actual work of constructing the system began in February, 1913, the work being carried out directly by the Company under the direction of its Chief Engineer.

This method of performing the work was followed until October, 1913, when the remainder of the work, except the pipes across gulches, was let out to Mr. Jorgen Jorgensen, Contract Engineer. Mr. Bishop resigned as Chief Engineer at this time, and Mr. C. H. Kluegel was appointed Inspecting Engineer to complete the work. Later Mr. J. M. Young was appointed as Consulting Engineer. The work is thus divided into two stages.

GENERAL PLAN

The general plan provided for collecting the water from the many streams and gulches on the windward side of Oahu by means of tunnels through the ridges or spurs, and conveying the water, after collecting, through the mountain in the main tunnel to the leeward side of the Island, thence by tunnels, ditches and pipes, to the upper levels of Oahu Sugar Plantation.

The tunnels connect up the various streams on the North side, and take in the water at the adits in the gulches. There are 27 of these tunnels on the North side, varying in length from 280 feet to 2332 feet, the aggregate length of the North side tunnels being 24,621 feet, or 4.66 miles, being in reality one continuous

tunnel. The number of adits at which water is taken in is 30, the intakes being located at the most advantageous points at the streams in the gulches.

The maximum elevation at which water is taken into the tunnel is 790 feet above sea level, and the grade or slope of the North side tunnels is 1.3 feet per thousand.

The length of the main tunnel through the Koolau Ridge is 14,567 feet, or 2.76 miles, the grade or slope being 2.0 feet per thousand.

The elevation of the North portal of the main tunnel is 752 feet above sea level, and at the South portal 724 feet.

The length of the tunnels on the South side is 19,211 feet, or 3⅝ miles, this distance comprising 14 tunnels, varying in length from 346 feet to 3329 feet.

In these tunnels the slope or grade is somewhat less, being 1.3 feet per thousand, thus delivering the water at the lower end of the South side tunnels at an elevation of 699 feet. From this point the water is conveyed by means of cement-lined open ditches, elevated concrete ditches, four steel pipes, and three redwood pipes. It is delivered to the upper boundary of Oahu plantation at an elevation of 650 feet through several distributaries, and by the main ditch, which reaches this elevation at the boundary of Honouliuli.

The water is also delivered into numerous reservoirs, especially at night, when irrigating the cane fields is inconvenient. One of the larger reservoirs, on the line of the Waikakalaua storm water ditch, has long been in use. It is called Five Finger Reservoir. Its elevation was a determining factor in establishing the grade elevation of the Waiahole conduit.

The length of open ditch between the last tunnel and the Waikakalaua gulch is 20,000 feet, or 3.79 miles. This portion of the waterway crosses three gulches, where riveted steel pipes are used, ditches being impracticable.

The first of these pipes is 78 inches in diameter, and 1125 feet long, the maximum head being 165 feet. The second pipe is 78 inches in diameter, and 331 feet long, the maximum head being 80 feet. The third pipe, at Kipapa Gulch, is 72 inches in diameter, and 2034 feet long, and the maximum head is 270 feet. The fourth pipe crosses Waikakalaua Gulch. It is 72 inches in diameter and 970 feet long, the maximum head being 220 feet. This pipe crosses two tracks of the Oahu Railway, passing over one track and under the other. The aggregate length of the four steel pipes is 4460 feet to the West side of Waikakalaua Gulch.

The pipes are made of steel plates varying from ⅝″ thickness for the highest heads to ¼″ thickness for the upper sections. The

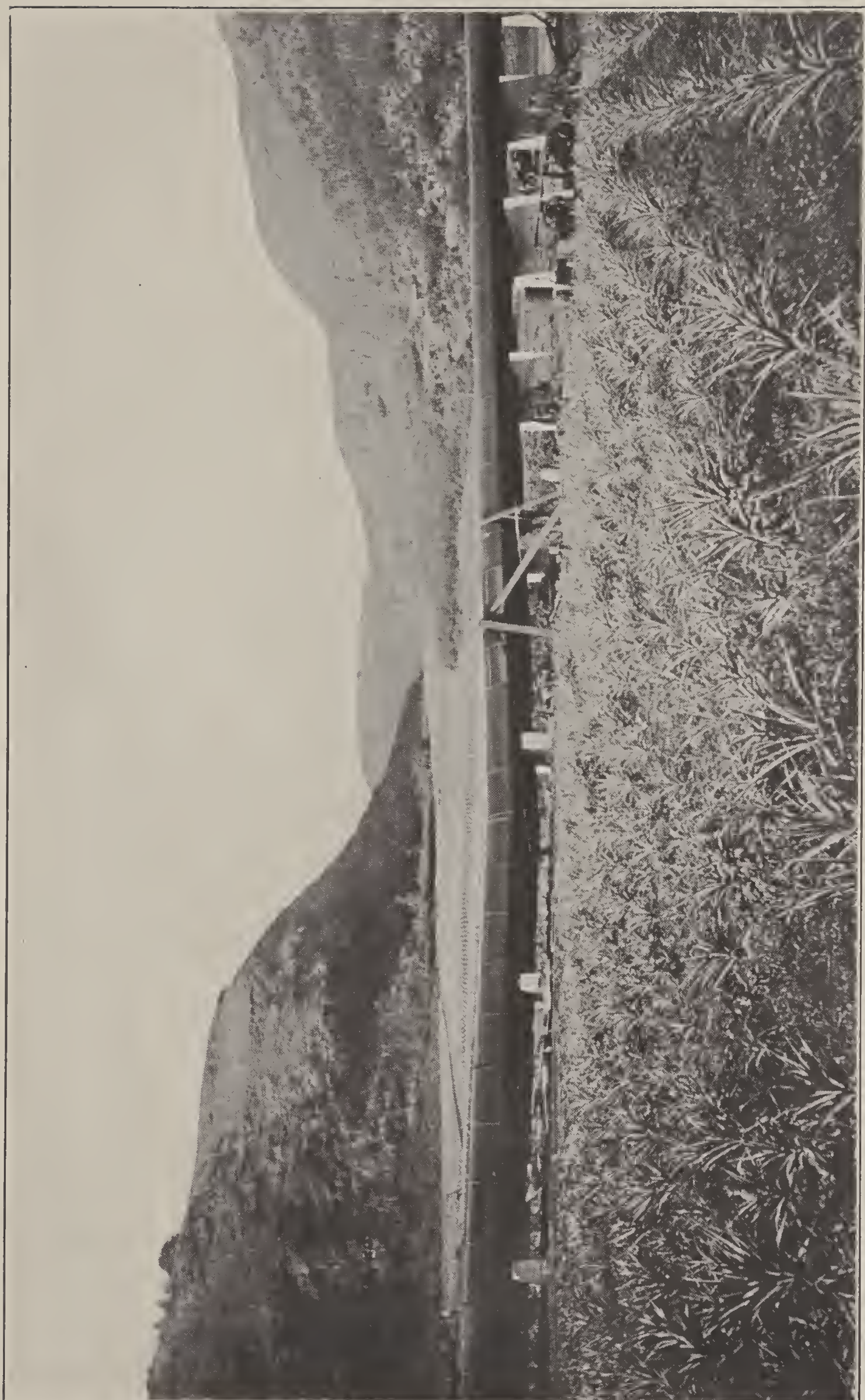
pipes are riveted together in five and one-third-foot sections. They are supported on concrete piers of varying heights, depending on the topography of the ground, and the spacing of the piers is, in general, about 26 feet, the spacing being chosen in multiples of section length.

The intakes and outlets of these pipes consist of a heavy construction of concrete, reinforced, and the intakes are provided with iron grating bars to prevent the access of floating material of any kind, and as a safety precaution in case of a person or animal accidentally falling into the ditch near the pipe.

72-inch steel pipe across Waikakalaua Gulch, looking west.

The pipes are provided with blow-off valves at the lowest points, and with man-holes for inspection, cleaning and painting, it being recognized that to keep steel pipes of this kind in good condition requires careful and thorough painting at frequent intervals.

Provision is made by means of valves at the lowest point of the Kipapa Gulch pipe to take out water for irrigating the lands in Kipapa Gulch, and other lands lying below that level, and also for power purposes, should this latter become desirable at some



72-inch steel pipe across bottom of Kipapa Gulch.

future time; the water from the tail-race of the power plant being then available for irrigation after delivering up its power, the available hydraulic head at this point being 280 feet.

West of Waikakalaua Gulch, through Hoaeae and to the upper boundary of Oahu Plantation in Honouliuli, the conduit consists of 12,650 feet of cement-lined ditches, and three redwood pipes 5 feet in diameter, having an aggregate length of 2830 feet.

SUBDIVISION OF WORK

For convenience in administration, the project was subdivided as follows:

North Division Tunnels	24,621	ft.	4.66	miles
Main Tunnel	14,567	"	2.76	"
South Division Tunnels	19,211	"	3.64	"
South Division Ditch	20,000	"	3.79	"
Pipes	7,290	"	1.38	"
Hoaeae Ditch	12,650	"	2.40	"
Honouliuli Ditch		approx.	2.	"
Distributaries		approx.	6.	"
Total			26.53	miles

not including extensions by Oahu Sugar Co.

ORGANIZATION

When the work was undertaken, the time of completion was considered an important element, and Mr. Bishop's organization was planned to secure the most expeditious execution of the project.

The office of the Chief Engineer was located in Honolulu, where all plans were drawn, all maps were made, and records kept. The purchasing of material and the accounting were also done at the main office. The force in this office consisted of an Assistant Engineer, whose work was chiefly on plans and in preparing designs under the direction of the Chief Engineer; draughtsmen, clerks, and stenographer.

Reporting to the Chief Engineer were two Division Engineers—one located at each portal of the main tunnel, each Division Engineer having two parties in the field, each party consisting of a chief of party, transitman and rodman, and each division office had the services of a draughtsman for plotting up the notes and recording the data brought in by the field parties, all data being

sent in to the main office as soon as checked and worked up.

Also reporting to the Chief Engineer was a General Superintendent of Construction, Mr. A. A. Wilson, who was in direct charge of all the constructing work.

Reporting to the General Superintendent were two Assistant Superintendents, one located at each portal of the main tunnel, and each having in charge the tunnel foreman, the shift bosses, and the gangs of tunnel men.

At the beginning of the tunnel work, three shifts of eight hours each were kept going. This was continued until the large amount of water coming into the tunnel, at North heading, became troublesome, and on account of the hardship on the men, working for eight hours in the cold water, it became necessary to cut the shifts down to six hours each, so that four shifts per day were employed for this heading.

The temperature of the water in the tunnel was approximately 66° F., or about 8° colder than the artesian water in Honolulu, or, roughly, about 1° for each 100 feet of elevation.

Great care was exercised in checking the surveys, the triangulations and the levels. This was given special care on the main tunnel, it being realized that while a small error in alignment would be unimportant, it would be necessary that all levels be correct. This levelling was done in the field by three separate parties, each of which went over the line twice, checking his own work, and the results of all three parties were checked against each other and found to compare within very small limits, thus eliminating any possibility of error. The instruments used for this work were thoroughly adjusted and tested for accuracy.

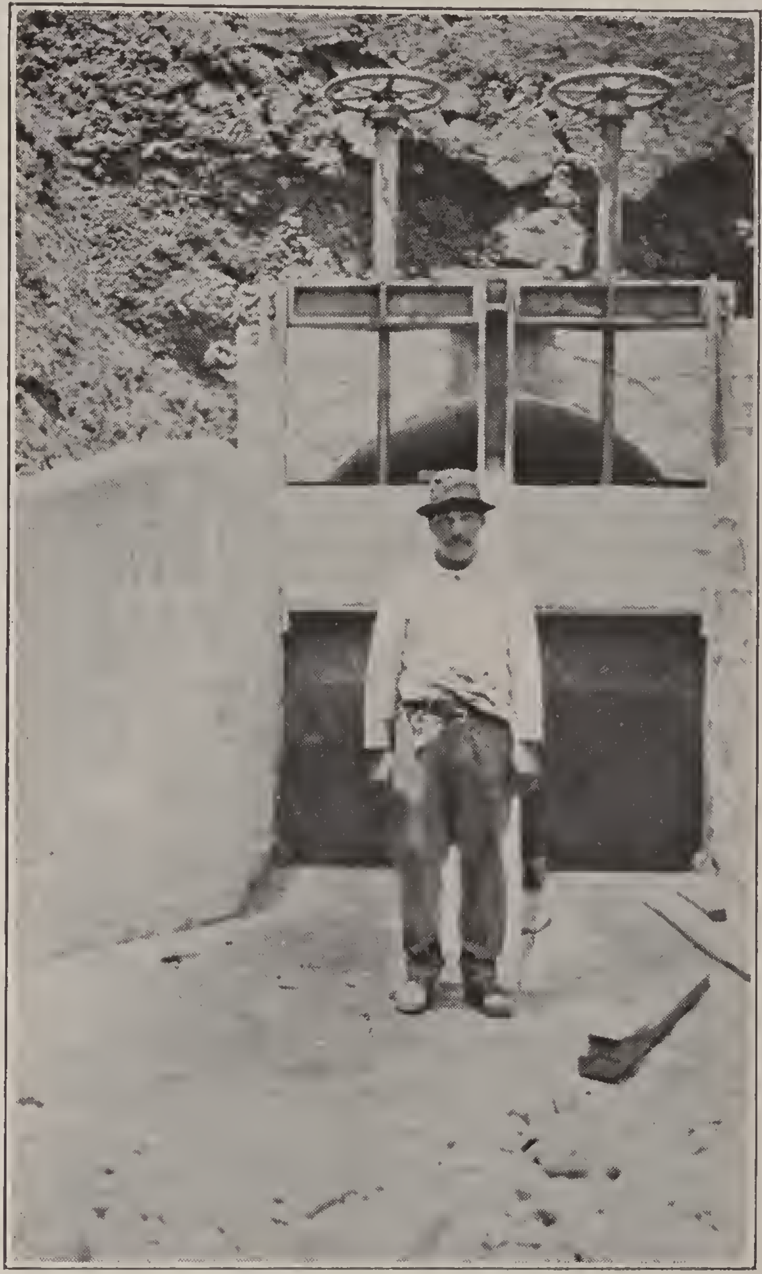
The work on the main tunnel was started at once after the surveys were checked and found correct, and was done at first by hand in order to save time and push the work along as far as possible pending the arrival and installation of the air drills and machinery.

It was of importance that bases of supplies be established at each portal, so all possible speed was made in constructing the railway from Waikane landing to the North portal and the railway from Pump 6 at Oahu Plantation to the South portal.

In the meantime, camps were established and sanitary conveniences were built to comply with the requirements of the Board of Health. No serious sickness, such as typhoid fever, gave any trouble.

With the above organization, the surveys were made and checked, the plans prepared, the transportation line, consisting of six miles of track leading to the South portal from Pump 6, and three and a quarter miles of railway from Waikane landing to

the North portal, was built; camps were built; work was laid out in the field; the power plants and machinery were installed, and the actual work of excavation and construction were well under way on October 1st, 1913, when this arrangement and organization was terminated.



Gates at a section of finished conduit.

The actual amount of main tunnel then driven was 912 feet on the North side and 2050 feet on the South side, or about 20% of the length of the main tunnel was driven under the direction of Mr. Bishop. Some work was also done on the lateral tunnels on both sides, but this part of the work was not rushed so much as the work on the main tunnel, inasmuch as the time required for the latter was the governing factor which controlled the date of completion.

INTERFERENCE BY WATER

While it was suspected at the outset that considerable water might be encountered in the main bore through the mountain, it was not anticipated at the beginning that enough water would be developed to materially interfere with the progress of the excavation. This hope was not realized, however, for the main bore had proceeded only about 200 feet from the North portal when water to the extent of two million gallons daily was developed—this on breaking through the first dyke.

These dykes are hard, impervious strata of rock lying approximately at an angle of 45° to the tunnel axis, and nearly vertical, and they occur at intervals of varying length. Between the dykes was the porous water-bearing rock, thoroughly saturated, and with the water pent up between the dykes often under considerable pressure, so that when a dyke was penetrated, the water would spout out from the drill holes and would gush forth from the openings blasted in the headings. As the work progressed, the water increased in quantity and the difficulty of the work was enormously greater on account of the water.

The slope of the tunnel being downward from the North portal, the matter of getting rid of the water by drainage was also one of great difficulty. This at first was managed by lowering the floor at the North portal about 2 feet, this being thought sufficient at that time, and allowing the water to drain out by gravity.

At about 900 feet from the North portal, the flow of water having increased to 26 million gallons daily, the floor was again lowered to five feet below grade at the portal, and at this stage the men in the heading were working waist-deep in cold water, in a perfect torrent, the inflowing water coming principally from the face and from the roof and sides for a distance back from the heading, the flow of water apparently following the heading fairly closely. The pressure of water in the drill holes interfered very much with the blasting, so that the ordinary methods of charging and firing could not be used. The final expedient resorted to to hold the dynamite in place until it could be fired was to pack the sticks of explosive in thin metal tubes of the diameter of a stick of powder, and of sufficient length to enclose the quantity of powder desired. This scheme gave good results, but was expensive and materially delayed progress.

The texture and hardness of the rock varied considerably—some of it being particularly soft and porous and much of it hard and flinty—particularly at the dykes. The dykes varied in thickness from 14 feet down to about 4 feet, but all the dykes were composed of very hard, close-grained rock which was ap-

The Lord-Young Company's wagon train hauling 72-inch pipe sections.

parently waterproof. All of the rock, however, was gritty and abrasive lava, and necessitated an unusual amount of drill sharpening, two of the latest type drill-sharpening machines being kept busy all the time.

When the water had increased to the point where it could not be drained out by gravity by lowering the floor at the North portal, a siphon pipe made of redwood, and 16 inches in diameter, was installed, and this made it possible to drive the work ahead a short distance further. A second siphon pipe 20 inches in diameter was next installed at the side of the tunnel immediately over the top of the 16-inch siphon, and this gave further relief and made it possible to extend the North heading to approximately 1400 feet. At this point the maximum inflow of water was approximately 35 million gallons daily, which was taken out by the two siphons and gravity drainage.

It was seen that the siphon method alone would not suffice for further drilling, so a relief or drainage tunnel was driven on the West side of and parallel to the main tunnel at a slightly higher level and on an ascending slope from the portal, its object being to intercept and drain off a portion of the troublesome inflowing water. This tunnel was required to provide access at all times to the water register to be installed at the boundary between Waiahole and Waiawa, distant 1705 feet from the North portal. This expedient proved helpful after the tunnel was extended in about 1400 feet. The two tunnels were then worked together alternately, first one and then the other, the floor of the main tunnel being kept above grade to avoid having the tunnel men work so deep in the water. They were working at this time in water about three feet deep.

This alternate working was continued to 1700 feet from the North portal, where a chamber was blasted out of the solid rock on the side next to the relief tunnel. A cross-cut was made to connect the two, and a centrifugal pump of 13 million gallons capacity was installed, which raised the water of the main tunnel through a pipe to the relief tunnel, which, at this point, is some 18 feet higher, and the relief tunnel acted as a drain.

With this arrangement, the work proceeded until the two headings met on December 13, 1915, and although the trouble and difficulty with the water never entirely ceased, it was possible to proceed slowly at an average rate of about 12 feet per day of 24 hours with three shifts.

SOUTH HEADING, MAIN TUNNEL

From the South portal the progress was rapid, often as high as 630 feet per month, or about 21 feet per day on an average,

Water issuing from water-bearing rock in the main tunnel, 10,550 feet from the South Portal. March 23, 1915. (The lanterns are held by men standing alongside a Leyner drill)

notwithstanding the long haul, which at the last was over two miles.

The first dyke on the South side was struck at 10,518 feet from the portal, the first evidence of water being from the drill holes, from which the water spouted under pressure.

The measurements of pressure by gage on some of the plugged drill holes showed a pressure of 65 pounds per square inch, corresponding to a static head of 150 feet. When water was struck, the excavation was discontinued temporarily. The spouting drill holes were plugged, the track was removed, and the floor of the tunnel, which up to this point was mainly through porous rock, was lined with concrete with a plastered cement surface; the walls in the meantime having been lined and cemented to make them watertight. Such portions of the tunnel as required overhead arching had been arched and made ready for use.

The track was then replaced and the work continued at reduced speed, due to the water, which came in in large quantities, the maximum flow from this heading reaching 17 million galons daily, until the two headings met at 11,679 feet from the South portal.

From the foregoing it will be seen that 80% of the length of the main tunnel was driven from the South portal, and 20% of the length was driven from the North portal, the difference in these proportions from the two headings being due to the presence of water at a much earlier stage in the North heading. Had there been no water to contend with, the length driven from each heading would have been approximately the same.

In order to give room for the water to flow from the heading, the track was raised on timbers of 4x12 in long lengths, placed edgewise as stringers, on top of which the track ties were laid. The track was 24″ gage, laid with 16-pound and 20-pound T-rail. The cars used were the standard Koppel one-yard, all-steel dump cars. Electric locomotives driven by storage batteries were used in both headings. These gave good service on short hauls, except for the necessity of frequent recharging of the batteries, and minor difficulties due to water.

A gasoline motor tractor was used for the long haul, until the track was raised in the South heading, the raising of the track leaving insufficient clearance for the gasoline locomotive.

A cable haul was then installed, this operating entirely without interruption from the water and clearance. The steel cable used was one-half inch in diameter, and was approximately four miles in length, spliced to make a continuous cable, and running over a sheave secured to a timber in the floor of the tunnel at 10,800 feet from the South portal. The cable tractor was a

Portion of tunnel, showing forms for arch of tunnel roof.

double-drum puller with a cable tightener, and was driven by belt and gearing from a 50 H. P. electric motor. There was considerable wear on the cable, due to abrasion on the ties. This wear was much reduced by damming up the water in the tunnel at frequent intervals in order to permit the cable to run in the water, which, apparently, acted as a lubricant and reduced the

wear. The cable parted on two occasions, and delayed the work until a splice could be made. One cable was completely worn out and the second cable used was probably about half worn out, over a period of eight months.

POWER PLANT

At the outset it was planned by Mr. Bishop to supply electric power to the two portals for operating the air compressors and other machinery from a central power station, located at Pump 6, transmitting at high voltage by pole line to the two portals, the pole line extending past the South portal over the mountain to the North portal.

This station was installed and the power line was built from Pump 6 as stated, but before it was completed, water had been struck on the North side, and the quantity was found to be sufficient to supply all the power needed, the available convenient hydraulic head being approximately 250 feet. The central steam-driven power plant was completed, however, and held at reserve for emergency use, although the plant and power line from Pump 6 to the South portal was used very little. The central power plant consisted of 500 H. P. Babcock & Wilcox water-tube boilers, supplying steam at 180 lbs. pressure, to a 350 K.W. high-pressure non-condensing steam turbo generator set, delivering 3-phase current at 3300 volts pressure, stepped up and transmitted at 11,000 volts to the two stations at the portals, and there stepped down to 250 volts for use at the motors. Oil fuel was used for the boilers, and the location at Pump 6 was chiefly on account of the convenience of fuel supply, which was drawn from the tanks supplying fuel to the boilers at Pump 6.

The plant which actually supplied the power for use at the tunnel was a 350 H. P. Pelton water-wheel belted to 300 K.W. 3-phase generator, these units being installed in the gulch below and near the North portal.

There was an abundance of water from the North heading, and the head at the Pelton wheel was 250 feet. This made an inexpensive and easily operated plant which was entirely satisfactory except at rare intervals when the water was low. The power was transmitted by pole line to the South portal in the opposite direction to that originally planned.

The local plant at each portal contained a duplex 2-stage Ingersoll-Rand air compressor, supplying 800 cubic feet of free air per minute, at a pressure of 100 pounds per square inch, belted to electric motors; receivers; Leyner drills; sharpening machine; pumps; blacksmithing equipment; blowers for ventilation; a num-

ber of small machine tools for repair work, and facilities for making up the metal powder tubes. The air drills used were the water-Leyner drills up to 10 feet long. These drills use a jet of water under pressure which forces out the cuttings from the point of the drill. They are capable of rapid drilling, there being very little interruption from the clogging up of cuttings.

Air was supplied to the drills by a 4-inch pipe line running to a manifold which was always near the heading. Each round required from 12 to 20 holes, eight to ten feet depth, the holes being drilled at slightly converging angles in order to break the rock effectively. Each round required from 50 to 100 pounds of 40% or 60% dynamite, Giant brand being used.

Steel pipes at Waikakalaua Gulch, crossing a branch of the Oahu Railway. The larger one is the new 72-inch pipe.

The ventilation of the tunnel headings was secured by forcing air by means of blowers through 16-inch metal pipes which were carried along the side of the tunnel, the air being forced in continuously. When a shot was fired, the direction of the blower was reversed for a while, and the smoke and foul air was drawn

out of the tunnel through the pipe until it was clear and fit for the men to work. This arrangement of ventilation proved effective and saved a great deal of time.

LABOR

Special tribute should be paid to the Japanese tunnel men, without whom the excellent progress made on the tunnel would have been impossible. These "professional" tunnel men, as they

Japanese professional tunnel men, Main Tunnel, July, 1914.

call themselves, prefer this work to any other, and they apparently take delight in the hardships incident to the work, the exposure to the cold water, and the risk in handling explosives. They were on the job all the time and never failed to deliver the goods in situations in which white men or native Hawaiians would have been physically impossible. Most of the drilling and mucking was done by these tunnel men as sub-contractors—a bonus being given for rapid work, which sharpened their interest and never failed to give results.

CAPACITY OF CONDUIT

The size of tunnel section is approximately 7 feet wide and 7 feet high, but in many places the section is larger, due to the uneven cleavage of the rock, and the fact that certain portions are unlined. The capacities of different portions of the conduit are as follows:

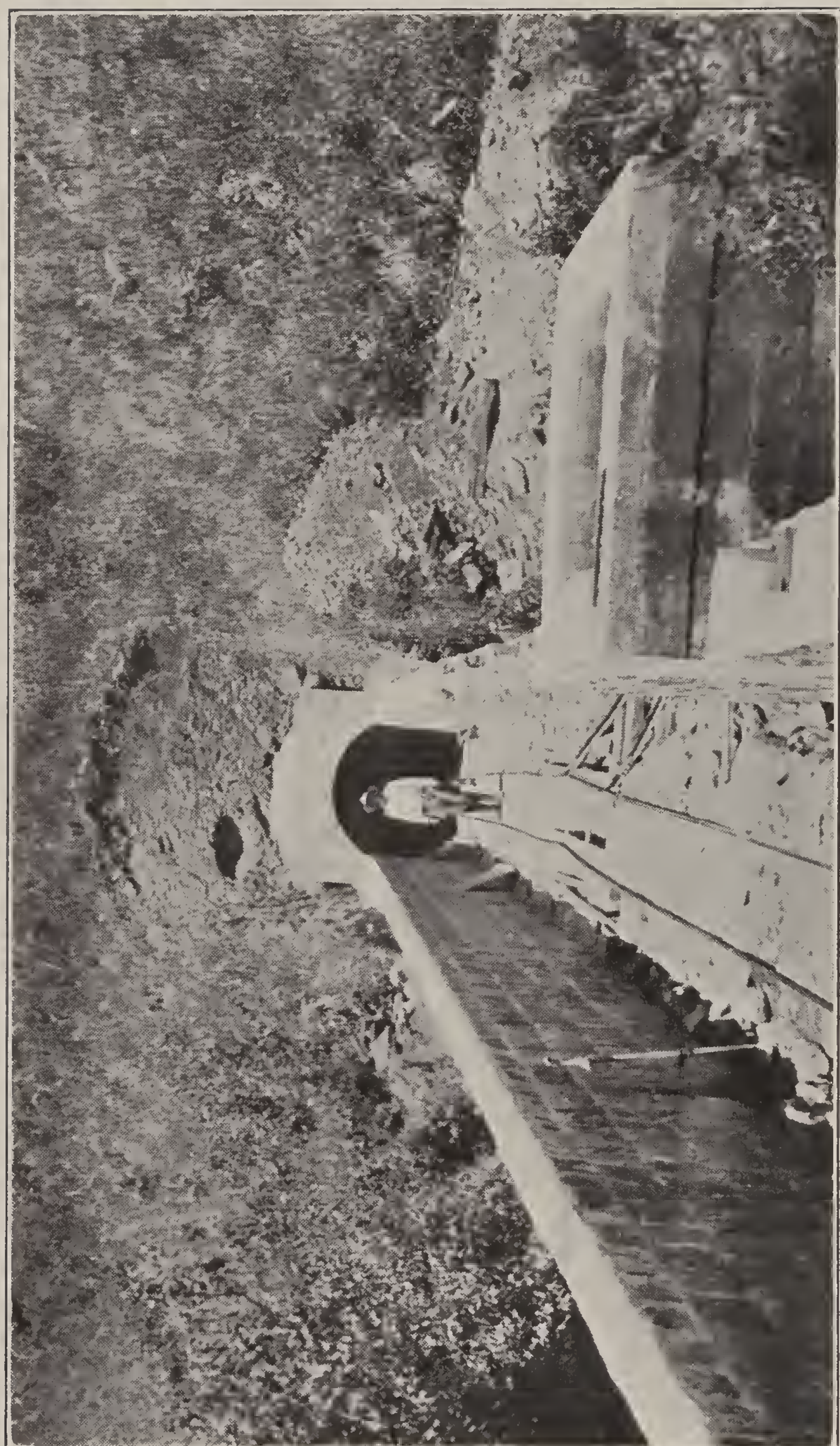
Tunnels 18-27 North side	80	million gallons daily
Tunnels 13-18 North side	100	do.
Tunnels 1-13 North side	115	do.
Main tunnel	150	do.
Lateral tunnels South side	125	do.
Pipes and ditches to Kipapa Gulch	125	do.
Pipe across Kipapa Gulch	100	do.
Ditches beyond Kipapa Gulch	100, 140 and 40	do.
Pipes beyond Kipapa Gulch	100 and 40	do.

72-inch steel pipe, Kipapa Gulch.

The capacities of the various parts of the conduit are affected to a considerable extent by the slope or grade. The tunnel section was governed to a very large degree by the minimum size in which the most rapid work could be done, and in general the section for this reason is greater than the 7-feet size specified.

MEASUREMENT OF WATER

The main bore through the mountain was intended at the beginning to be merely a conduit to convey the water from one side to the other, but in the process of building the tunnel, water



Location of water-measuring station between lateral tunnels H and I, Waiawa Gulch.

was developed so that this became a source of supply, and for this reason it is necessary to measure the flow at certain boundaries as a basis of payment for the water to the owners of the land. Two stations for the measurement of water are operated, one at the boundary of Waiahole and Waiawa, and one between lateral tunnels H and I on the South side, measurements at these points being all that are required for payment of the water. These stations are in channels of uniform sections which are rated, and the stage of water is recorded by an automatic water-stage register, thus giving a permanent record of the daily flow as a basis for payment.

Open ditch in Waiawa, with cement lining.

The maximum quantity of water developed was on October 16, 1914, and was approximately 35 million gallons daily from the North portal. The flow of water has varied considerably from time to time, and has been decreasing, apparently indicating that the water stored in the mountain between the dykes is gradually being drained off. It is thought that the permanent or continual flow from the tunnel bore will be governed by the rainfall over this drainage area. The present flow of water percolating into the main tunnel is 14 million gallons daily. This appears to be the dry weather flow.

CLOSED CONDUIT SYSTEM

This system of tunnels is essentially a closed-conduit system—that is, the flow is entirely through closed tunnels, not subject to

interruption by freshets or washouts or from rubbish or wash from the mountain streams, the intakes being so built as to admit only water as free from rubbish as practicable. Only at three points in the tunnel system—and these are on the South side, one of which is a gaging station—does the water flow in open channels for an aggregate length of 160 feet.

Pipes were not a part of the contract to Mr. Jorgen Jorgensen. Steel pipes were let out to contract to the Lord-Young Engineering Co. The last of these pipes has just been completed. The contract for the redwood pipes was let to Lewers & Cooke, Ltd.

It is intended to use the reservoirs so far as possible to take care of the water flowing at night, so as to utilize the conduit to its fullest capacity.

The Waiahole Water Co. has taken over from the Oahu Sugar Co. the Ahrens Ditch in Waiawa, the Kipapa Ditch, the Waikakalaua Ditch in Waipio, and the Hoaeae Ditch. Two redwood pipes having total length of 1223 feet have been laid across two gulches on the line of Hoaeae Ditch, cutting out 2¼ miles of ditch.

The water delivered by the Waiahole System is chiefly used on newly-planted cane on land above the lift of the pumps. During construction the water developed in the main tunnel near the South portal was at times utilized for irrigation. On May 27, 1916, with Mr. H. Olstad as Superintendent, continuous operation of the project was begun.